Sept. 20, 1971 D. KING 3,605,863

APPARATUS FOR MANUFACTURING WIRE AND THE LIKE

Original Filed July 6, 1967 2 Sheets-Sheet 1

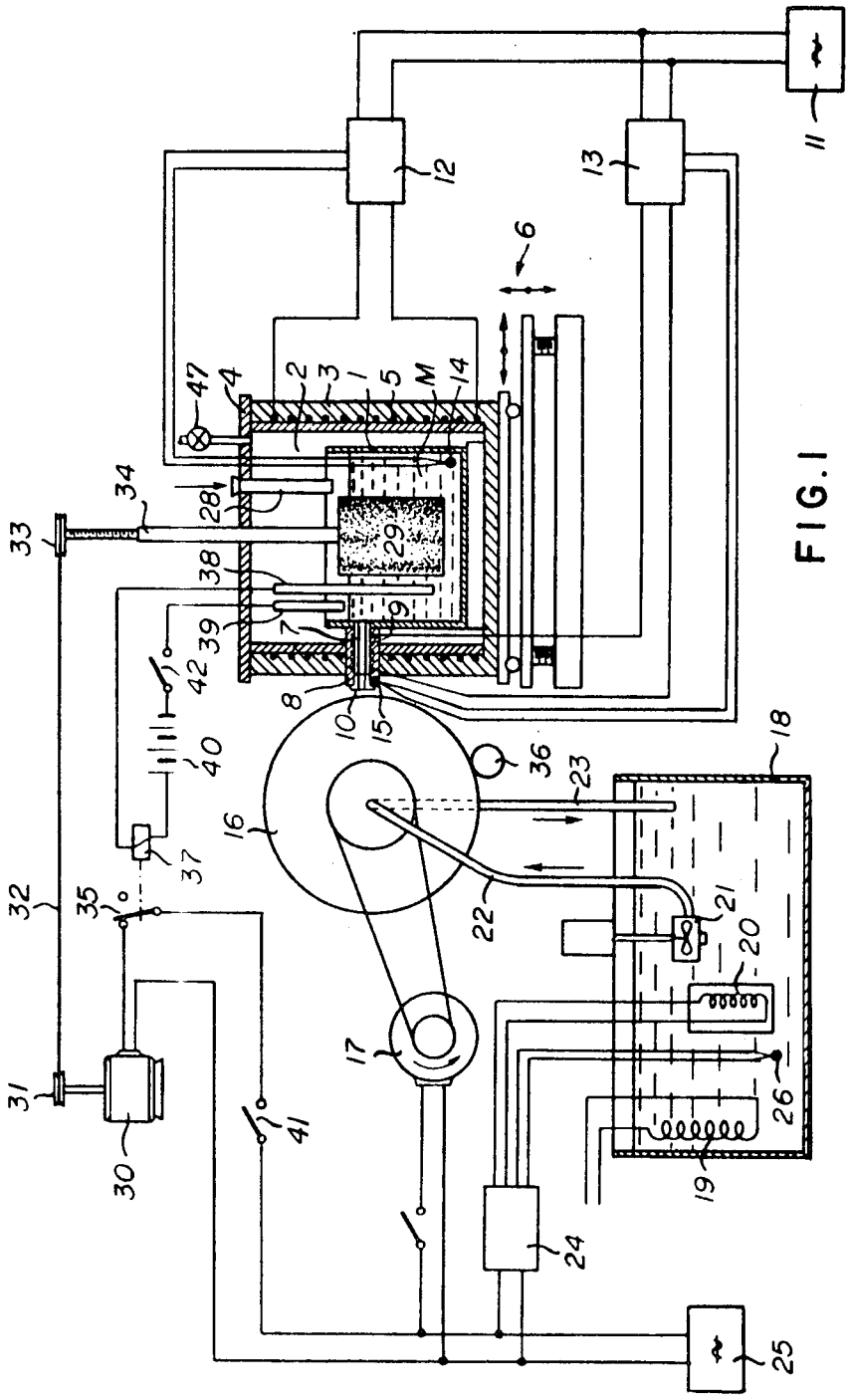


FIG. 1

APPARATUS FOR MANUFACTURING WIRE AND THE LIKE

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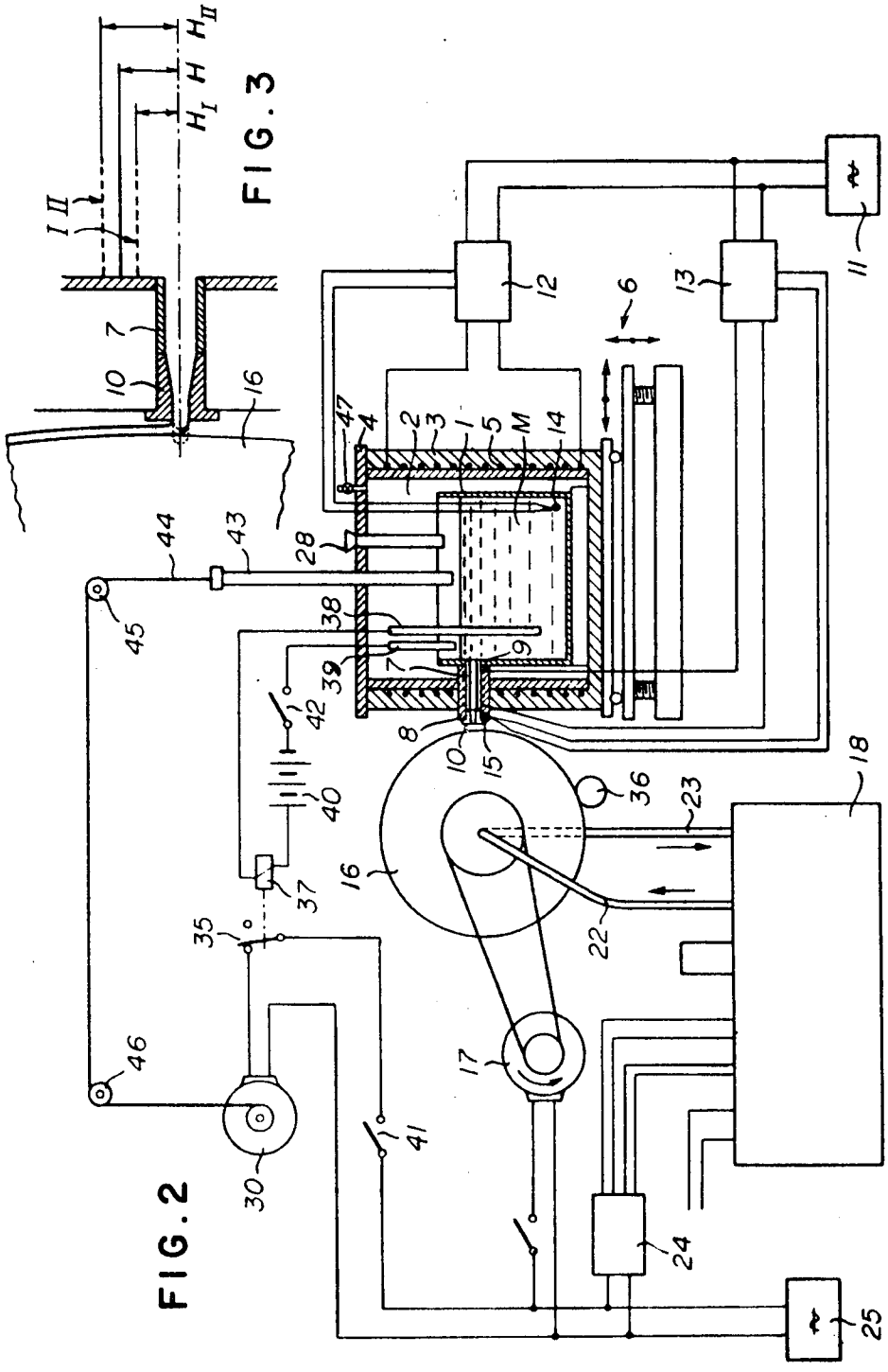


FIG. 3

FIG. 2

United States Patent Office 3,605,863 Patented Sept. 20, 1971

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APPARATUS FOR MANUFACTURING WIRE AND THE LIKE

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Original application July 6, 1967, Ser. No. 651,551, now Patent No. 3,522,836, dated Aug. 4, 1970. Divided and this application Sept. 29, 1969, Ser. No. 870,880
Claims priority, application Switzerland, July 6, 1966, 9,991/66
Int. Cl. B22d 11/10
U.S. Cl. 164—156 4 Claims

ABSTRACT OF THE DISCLOSURE

Manufacturing wire and the like by maintaining static equilibrium in molten material at the outlet of a nozzle to form a convex meniscus from which the material is continuously drawn off and solidified by means of a moving surface at constant temperature.

This is a division of application Ser. No. 651,551, filed July 6, 1967 now Pat. No. 3,522,836 issued Aug. 4, 1970.

The present invention relates to manufacturing a continuous product such as a metallic wire or strip from a molten material.

The methods of manufacturing by drawing or rolling out, which are normally used for producing metallic wires and strips, require a great number of operations and relatively complicated installations adapted to each product.

Certain conventional continuous casting methods for metals consist in creating a flow of molten material which is directed towards a moving surface serving to solidify and remove said material continuously. Manufacturing a product in this manner from the molten material obviously presents considerable advantages, in particular an appreciable reduction of the number of operations required. To obtain a uniform product having given quality and dimensions, one must, however, be able to pour said metal at a controlled rate i.e. to control the metal feed speed in a precise manner so as to keep it always equal to the speed of removal of the metal by means of said moving surface. When, however, the desired product has a small cross-section, such as is the case for a thin metallic wire or strip, none of the known continuous casting methods allow the metal feed speed to be controlled in a sufficiently precise manner to produce a uniform continuous product.

In order to avoid this disadvantage, a method of continuous casting has been proposed which does not entail the usual pouring operation. This method consists in moving a mold which is open at the side downwards through a bath of molten material kept at constant level, whereby said material continuously fills the cavity of said mold. The material in the mold is subsequently cooled to form the desired product. The speed at which the molten material is capable of flowing into the mold is, however, rather limited, especially in the case of a product having a small cross-section. Furthermore, extraction of the product from the mold is difficult. Thus the method is not suitable for continuous, high speed production of such a product.

The object of the present invention is to provide a uniform continuous product, and in particular a metallic wire or strip having a small cross-section, to be continuously manufactured in a simple manner from a molten material. With this object in view, the method according to the invention, comprising bringing forward said molten material continuously to the outlet orifice of a nozzle and moving a surface past said orifice so as to form the desired product thereon, further comprises the steps of: maintaining said material at said orifice at a constant temperature and pressure, said pressure being chosen to provide static equilibrium to allow said material to form a convex meniscus projecting at said orifice; bringing said moving surface into contact with said meniscus to draw off said molten material continuously therefrom; and maintaining said surface at a constant temperature such that said material solidifies progressively thereon to form the desired product.

The principle on which the present invention is based thus consists in using a moving surface to effect a continuous "wiping" action on a meniscus formed by the molten material while maintaining the pressure in the latter within the limits corresponding to static equilibrium in order to allow replacement of the material removed by said surface. It is thus the speed of said moving surface which mainly determines the flow speed of the molten material. As will be seen below, the range of pressures extending between said limits is relatively large so that the conditions necessary for static equilibrium may be easily established, thus allowing stable flow and consequently a uniform product to be obtained in all cases.

The present invention relates to an apparatus for manufacturing a continuous product by said method. This apparatus comprises: a reservoir having at least one outlet pipe provided with a nozzle; means for maintaining said reservoir at atmospheric pressure; an adjustable heating device for maintaining said material, in said reservoir and in said pipe, at a constant temperature lying above the melting point thereof; a regulator for keeping the free surface of said material in the reservoir at a desired constant level lying above said pipe; a drum adapted to rotate about a horizontal axis such that the peripheral surface thereof moves continuously past the outlet orifice of said nozzle, at a given adjustable distance therefrom; first adjustable drive means for rotating said drum at a given speed; and means for delivering a stream of fluid at an adjustable temperature for circulation within said drum to keep said drum surface at a desired constant temperature.

The accompanying drawing represents, by way of example, an embodiment of an apparatus according to the invention as well as a variant of said embodiment, said apparatus being intended, in particular, for manufacturing a metallic wire.

FIG. 1 is a vertical cross-section of said embodiment.

FIG. 2 shows a variant of the apparatus represented in FIG. 1.

FIG. 3 shows schematically, on a larger scale, a detail of FIGS. 1 and 2.

The device represented in FIG. 1 comprises a reservoir **1** of refractory material such as alumina, which is open at the top and arranged within a chamber **2** formed by insulating walls **3**, **4**. This chamber **2** is equipped with an electrical heating element **5** and forms a furnace resting on an adjustable support **6**. A horizontal outlet pipe **7**, likewise of refractory material e.g. alumina, is mounted on the reservoir **1** and passes through the side wall of the chamber **2**. This pipe **7** is surrounded by an insulating jacket **8** and by an electrical heating element **9**. A nozzle **10** having a free cross-section adapted to the profile of the desired product is mounted at the outlet of the pipe **7**. As may be seen in FIG. 1, the reservoir **1** contains molten metal M having a free surface situated at a given small height above the pipe **7**.

The heating elements **5** and **9** are connected to an A.C. source **11** by means of control devices **12** and **13** which regulate respectively the heating currents passing through said elements. Two thermo-couples **14**, **15** serve to measure the temperature of the molten metal in the reservoir **1**

and at the outlet of the pipe 7 respectively and to control operation of the control devices 12, 13 so as to maintain the material surrounding said thermo-couples at predetermined temperatures.

This apparatus further comprises a hollow steel drum 16 mounted on a horizontal shaft and rotatably driven by means of an adjustable-speed motor 17, the means for controlling the speed of said motor being omitted from the drawing. This drum 16 has a smooth peripheral surface and is arranged so that this surface moves upwards, at a given constant speed, past the outlet orifice of the nozzle 10. So as to allow the exact position of the outlet of the nozzle 10 with respect to the peripheral surface of the drum 16 to be determined, according to the product to be manufactured, the support 6 on which the furnace rests further comprises two mechanisms (not shown) serving respectively for horizontal and vertical displacement of the furnace. Furthermore, said drum surface is kept at an appropriate constant temperature by means of a stream of water circulating within the drum 16, said flow being supplied by a constant-temperature water-bath 18. This bath comprises a coil 19 in which cold water circulates continuously, an electrical heating element 20 and a pump 21 adapted to continuously circulate water, by the supply and return conduits 22 and 23 respectively, between the bath 18 and the drum 16. A control device 24 further serves to regulate the heating current delivered to the heating element 20 from an A.C. source 25, as a function of the water temperature measured by means of the thermo-couple 26, such that a constant desired temperature is maintained in the bath 18.

The wall 4 forming the cover of the chamber 2 is provided with an inlet pipe 28 which serves for the introduction of a charge of molten metal into the reservoir 1. This pipe further serves to maintain the chamber 2, and consequently the reservoir 1 at atmospheric pressure during operation of the apparatus.

The level of the free surface of the molten metal in the reservoir 1 is controlled by means of a regulator comprising a piston 29 driven by an electrical motor 30. As may be seen in FIG. 1, this motor 30 is connected to the piston 29 by means of a conventional transmission and reduction mechanism formed by a pulley 31 fixed to the shaft of motor 30, an endless belt 32 and a second pulley 33 co-operating witha vertical shaft 34 to which the piston 29 is fixed. Well known means (not shown in FIG. 1) comprising, in particular, internal and external screw threads arranged respectively on the pulley 33 and at the upper end of the shaft 34, allow the rotational movement of the pulley 33 to be transformed into a linear vertical movement of the piston 29.

The operation of motor 30 is controlled by a switch 35 arranged in the supply circuit thereof which is connected to the A.C. source 25, said switch 35 being actuated by excitation of a relay 37. Two electrodes 38, 39, of which one (38) is adapted to be immersed in the molten metal and the other (39) is arranged so that the lower end thereof is situated at the desired level of said metal, are connected in series with the energizing coil of the relay 37 and a D.C. current source 40. Two switches 41 and 42 further serve to manually break the supply circuits of the motor 30 and the relay 37 respectively.

Thus when the surface of the molten metal is at the desired level, a galvanic contact is established, across the said metal, between the electrodes 38 and 39, whereby the energizing circuit of the relay 37 is closed and the motor 30 is stopped by means of the switch 35. When, however, the surface of the metal is situated below the desired level, said galvanic contact is interrupted, the relay 37 becomes deenergized and the switch 35 closes. The motor 30 now being supplied with current, it drives the piston 29 so that the latter is moved downwards progressively and as a result the metal surface rises until it attains the desired level once more and causes the motor 30 to be stopped.

The apparatus further comprises a wiping member 36 for cleaning that part of the drum surface which is about to come into contact with the molten metal.

As may be seen in FIG. 2, the variant differs from the embodiment according to FIG. 1 only with regard to the means for regulating the level of the molten metal. Thus identical components already described with reference to the first embodiment have the same reference numerals in FIGS. 1 and 2.

The regulation of the level of the molten metal is obtained, in this variant, by means of a bar 43 of the metal intended for manufacturing the desired product, said bar being connected by means of a flexible cable 44 passing around two pulleys 45, 46, to an electric motor 30. The latter is controlled in the same manner as described above with reference to the motor 30 of the embodiment shown in FIG. 1 and thus serves to move the bar downwards progressively when the surface of the metal lies below the desired level. As a result, the lower part of the bar 43 is immersed progressively in the molten metal and brought into the molten state so that the surface of the molten metal rises up to the desired level. Once this level is reached, the galvanic contact is established between the electrodes 38 and 39, the motor 30 stops and the downward movement of the bar 43 is interrupted.

The pipe 28 may also be used for the introduction of an inert gas such as argon substantially at atmospheric pressure so as to prevent oxidation at the metal surface.

FIG. 3 shows schematically the manner in which the metal is drawn off, from the meniscus formed at the outlet orifice of the nozzle 10, by means of the drum 16. As may be seen in this figure, the meniscus (represented by dotted lines) may be more or less curved according to the height H of the metal level above the pipe 7, i.e., above the axis of the outlet orifice of the nozzle 10. The height H which is maintained while manufacturing the product is chosen between the extreme positions I and II corresponding respectively to the minimum pressure for forming a convex meniscus and the maximum pressure constituting the limit of static equilibrium, beyond which the meniscus breaks and, consequently, the metal pours out of the nozzle 10.

The maximum height H_{II} (in cms.) may be estimated in most cases, for nozzles with outlet orifices having small vertical dimensions of the order of a few millimeters, by means of the following formulae:

(a) For circular outlet orifices

$$H_{II}=\frac{2T}{R.\rho.g}$$

where:

T is the surface tension (dyne/cm.) of the molten material at the orifice

R is the radius (in cms.) of the orifice

ρ is the density (gr./cm.^{3}) of the molten material in the reservoir

g is the gravitational constant in cm./sec.^{2}.

(b) For rectangular outlet orifices having dimensions a x b (cms.), a being the vertical and b the horizontal dimension and a being much smaller than b:

$$H_{II}=\frac{2T}{a.\rho.g}$$

where T, ρ and g are the same as indicated above.

To manufacture a given product by means of the apparatus described above, one proceeds as follows:

After having mounted at the outlet of pipe 7 a nozzle 10 having an orifice selected according to the section of the desired product, the heating elements 5, 9 are switched on so as to preheat the reservoir 1 and the pipe 7. The metal is next introduced slowly into the reservoir 1 so as to form therein a bath of molten metal at constant temperature, the surface of which rises progressively. When the level of the molten metal has attained a sufficient height above pipe 7 for the metal to form an appropriate convex meniscus at the outlet orifice of said

nozzle **10**, introduction of the metal into the reservoir **1** is stopped. The level which is chosen will obviously be situated between the limits I, II mentioned above, at a height giving a meniscus which is sufficiently curved to allow it to be brought into contact with the drum **16**.

The height of the electrode **39** is then adjusted so that the lower end thereof comes into contact with the metal surface which is situated at the desired level and the switches **41** and **42** are closed to allow the motor **30** and the relay **37** to operate.

The drum **16** is then heated to a temperature of at least 40° C. by means of the bath **18** and made to rotate with a peripheral velocity which corresponds to the desired feed velocity of the metal. The meniscus formed at the orifice of the nozzle **10** is next brought into contact with the peripheral surface of the drum by adjusting the horizontal and vertical position of the support **6**. So as to obtain the desired product, the various parameters, such as drum temperature and speed, metal temperature at the orifice and the minimum distance between orifice and drum may then be adjusted so that the molten metal is drawn off uniformly and the product solidifies progressively on a portion of the periphery of the drum **16**. Finally, appropriate take-off means (not shown) such as e.g. roll systems may be used to separate the solidified product from the drum **16**.

The product thus obtained may obviously be subjected to a drawing out or rolling operation so as to modify the shape or surface quality thereof.

The optimal operating conditions of the apparatus according to the invention may thus be easily determined in each case by varying, in turn, the temperature of the molten material at the said meniscus, the temperature of the moving surface adapted to carry off the material and the speed of said surface until the desired product is obtained.

It should be noted that the ratio $H_{II}:H_I$ of the limiting heights between which the liquid level may vary while manufacturing may easily be of the order of 5:1. It is thus obvious that the height H is not critical for manufacturing the product, provided it be kept between said limiting heights so as to keep the drum surface in contact with the meniscus.

It may also be mentioned that to the present invention allows the rate of solidification of the material on the moving surface to be controlled in a precise manner especially by regulating the speed as well as the temperature of this surface. This allows the crystalline structure of the product to be determined so as to confer desired mechanical properties to said product.

The apparatus described above has allowed various continuous products, in particular wires and strips of aluminum, the alloy known as anti-corrodal, copper and steel to be manufactured; these products had uniform dimensions and were of satisfactory quality.

EXAMPLE 1

For manufacturing uniform wires made of aluminium, copper and mild steel (1% C) and having a diameter of 2 mm., the apparatus is provided with a nozzle having a circular orifice with a diameter of 2 mm. and with a drum having a diameter of 200 mm. One then manufactures in the manner described above, while choosing the following values for the various parameters:

	Al	Cu	Steel
Metal temperature at orifice, in ° C.	720	1,150	1,600
Temperature of peripheral surface of drum, in ° C.	80	95	95
Rotational speed of drum, r.p.m.	60	60	60
Minimum distance between orifice and drum in mm.	0.3	0.3	0.3
Height (H) of metal level above nozzle axis, in mm.	10	10	10

The manufacturing speed, which is equal to the peripheral velocity of the drum, is about 38 meters per minute.

EXAMPLE 2

For manufacturing strips of anti-corrodal alloy (Al, 96.5 to 97.8%; Si, 0.5 to 1.5%; Mn, 0.2 to 1%; Mg, 0.5 to 1%) the same drum is used as in Example 1. So as to obtain two types (A, B) of strip having the dimensions 6 x 0.8 and 4.5 x 1 mm. respectively, the apparatus is provided with a nozzle having the following dimensions:

	Type A	Type B
Width in mm.	8	6
Height in mm.	1	1.5

One then manufactures in the manner described above, while choosing the following values for the various parameters:

	Type A	Type B
Temperature of alloy at orifice in ° C.	685	700
Temperature of peripheral surface of drum in ° C.	50	60
Rotational speed of drum, r.p.m.	10	7
Minimum distance between orifice and drum in mm.	0.8	1
Height (H) of alloy above nozzle axis in mm.	15	10

The manufacturing speeds were 6 and 4.4 meters per minute, respectively. It may be mentioned that these strips had a convex surface on the side opposite to that adhering to the drum. A single rolling operation, carried out on the drum itself by means of a roller exerting a pressure on the partially solidified strip, allowed, however, a product having a rectangular cross-section to be obtained, the faces of said product being perfectly smooth and the thickness thereof being easily adjustable by varying said pressure exerted by the roller.

It may be mentioned that the peripheral speed of the drum may be increased so as to obtain a product of smaller cross-section than that of the orifice.

The apparatus described above has also been used for manufacturing aluminum fibres of relatively short length by rotating the drum (**16**) at much higher speed than those indicated above.

It should be mentioned that the invention is also suitable for manufacturing a continuous product from other materials than those mentioned above by way of example. Thus materials may be considered particularly suitable which do not allow manufacturing by drawing or rolling, such as brittle intermetallic compounds having body-centered cubic crystal ("CCC") structures or metallic oxides.

It is obvious that numerous other variants exist of the apparatus. Thus, for example, instead of using a level-regulator to keep the surface of the material at the pressure necessary for forming a meniscus, it is possible to provide the apparatus with a device allowing the pressure of a gas in contact with the surface of the material in the reservoir to be controlled. This device serves to increase the pressure of the gas as the height of the metal level falls during operation of the apparatus, such that the pressure of the material be kept at the desired value at the orifice. This would allow a relatively high column, i.e. a larger reserve of metal in the reservoir by choosing a gas pressure below atmospheric pressure.

Furthermore, it is obvious that the nozzle serving to form the meniscus may be oriented in any other direction than the horizontal direction.

What is claimed is:

1. Apparatus for manufacturing a continuous product comprising: a reservoir having at least one outlet pipe provided with a nozzle; means for maintaining said reservoir at atmospheric pressure; an adjustable heating device for maintaining said material, in said reservoir and in said pipe, at a constant temperature lying above the melting point thereof; a regulator for keeping the free surface of said material in the reservoir at a desired constant level lying above said pipe; a drum adapted to

rotate about a horizontal axis such that the peripheral surface thereof moves continuously past the outlet orifice of said nozzle, at a given adjustable distance therefrom; first adjustable drive means for rotating said drum at a given speed; and means for delivering a stream of fluid at an adjustable temperature for circulation within said drum to keep said drum surface at a desired constant temperature.

2. Apparatus according to claim 1, wherein said regulator comprises a piston arranged for vertical movement by second drive means controlled by means of a detector arranged at the desired level of the surface of the molten material within said reservoir, such that said piston is moved and variably immersed in said material to annul any variation of the height of said surface relatively to said desired level.

3. Apparatus according to claim 2, wherein said second drive means comprise an electric motor adapted to move said piston in a downward direction until said desired level is attained.

4. Apparatus according to claim 3, wherein said detector

comprises at least one electrode arranged to have the lower end thereof situated at said desired level so that a galvanic contact is formed between said electrode and said material when the surface of the latter is situated at the desired level, said contact serving to stop operation of said motor.

References Cited

UNITED STATES PATENTS

905,758	12/1908	Strange et al.	164—87
2,799,065	7/1957	Whitaker	164—281X
2,963,739	12/1960	Whitehurst et al.	118—401X
3,201,275	8/1965	Herrick	118—401X
3,484,280	12/1969	Carreker, Jr.	164—281X

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